REMARKS

Claims 1-9 are in this application, with claims 1 and 7 having been amended for clarity.

Claim 9 has not been amended because it utilizes terminology know to those of ordinary skill in the art as will be evidenced by the known definition and publications identified below.

All of the claims are now submitted as satisfying 35 U.S.C. § 112, second paragraph. Claim 7 has been amended to comply with the requirements of 37 C.F.R. § 1.75(c) since it now includes the full context of the "adaptive" designation for the claimed method.

The known definitions of the claim terminology as set forth in relevant literature, are submitted to better clarify the claimed subject matter as follows:

Definition for "zero error", see Wikipedia / Sensors / Classification of measurement errors (http://en.wikipedia.ora/wiki/Sensor):

- If the output signal is not zero when the measured property is zero, the sensor has an **offset** or **bias**. 'this is defined as the output of the sensor at zero input.

Definition for "gain error", see Wikipedia / Sensors / Classification of measurement errors (http://en.wikipedia.org/wiki/Sensor):

- In the ideal situation, the output signal of a sensor is exactly proportional to the value of the measured property. The gain is then defined as the ratio between output signal and measured property. For example, if a sensor measures temperature and has a voltage output, the gain is a constant with the unit [V/K]. The gain may in practice differ from the value specified. This is called a **gain error**.

"gain factor" = identified factor (i.e., calculated factor) which is used for compensating gain error of the sensor, referred to below as G factor. G factor is a parameter (multiplier). Gain error is an internal property of the sensor (such as a tachometer) which depends proportionally on the value of the measured property, such as measured speed.

"zero factor" = identified factor (i.e., calculated factor) which is used for compensating sensor offset error (= zero error), referred to below as Z factor.

Zero factor (Zfactor) is a parameter. Zero error is a sensor internal property which is independent of the value of a measured property by the sensor.

The invention acts to continuously identify the gain factor (Gfactor) and zero factor (Zfactor) to compensate for gain and zero errors in the measured speed signal of a sensor tachometer ("taco") so that the measured tachometer output signal values are equal to the true values to an optimum extent.

The correction to achieve this purpose is a known two point calibration method for compensating gain and zero errors in measured signals (such as in analog/digital converters and the like). Two point correction is described for example in Application report: "Signal Acquisition and Conditioning with Low Supply Voltages" Heinz-Perete Beckemeyer, Texas Instruments Deutschland GmbH, June 1996 (see Appendix B).

Calculation is as follows (formula reference numbers refer to the Application Report above) and the parameters of the present invention are utilized in these calculations, as follows:

Transfer function (uncorrected)

S = Staco

Transfer function (with correction)

S = Staco x Gfactor + Zfactor   *see page 17, formula [14]*

where

S = corrected tachometer signal

Staco = measured tachometer signal without correction

Gfactor = gain factor (compensates gain error)

Zfactor = zero factor (compensates offset error)

where Gain factor is:

Gfactor = (Sref_up-Sref_down)/(Staco_up-Staco_down) *see page 17, formula [15] and Zero factor is formula [16]*

Zfactor = Sref_up-Staco_up x Gfactor *see page 17, formula [16]*

where

Sref_up = true speed (=speed reference) of the motor when elevator is running in the up direction

Sref_down = true speed of the motor when elevator is running in the down direction

Staco_up = tachometer signal when elevator is running up at speed Sref_up

Staco_down = tachometer signal when elevator is running down at speed Sref_down

The above solution is based on basic equations of straight lines defined by two points that can be found in most basic math books.

There are several ways to identify "true speed of the motor'. In a synchronous permanent magnet motor there is typically a sensor (for ex. Resolver) which gives absolute angular position of the rotor (Absolute position is needed for controlling rotating magnetic field of the motor). The absolute position of the rotor can be used for calculating "true speed of the motor". There are

also other possibilities to identify "true speed", however it is not relevant how "true speed" is identified in this invention.

Also, the specification says that "speed gain factor and speed zero factor are updated by a forgetting factor." This terminology means low pass filtering. The purpose of the filtering is to filter noise from the measurements (value of Gfactor and Zfactor are identified continuously). For example, in the simplest form filtering is as 1. order digital low pass filter:

Gfactor_new = (1 - K) x Gfactor_new + K x Gfactor_current

where

Gfactor_new = new identified Gfactor to be used for correction

Gfactor_current= current value of' Gfactor

K = filter constant (=forgetting factor), value between 0...1. In fact, this has already been explained in paragraph [0015] through [0021] of the specification.

The same filtering (=forgetting factor) applies to Zfactor calculations.

The above-identified articles have been downloaded from the Internet and are attached hereto as Appendices A (Wikipedia) and B (Beckemeyer, June 1996).

As can now be seen, Applicants have applied known mathematical correction techniques to provide optimized speed measurement for synchronous permanent magnet motor drives for imparting accurate upward and downward travel to a load driven thereby.

The parameters are determined by the nature of the load and its travel direction. Applicants have established that pursuant to the teachings of the invention, once the claimed parameters are determined, then known mathematical techniques are applicable and available to

those of ordinary skill in the art to make the corrections to measured speed value to compensate for drift in the feedback sensor used to measure that speed.

Because of the terminology used and the definitions and mathematical techniques available in the literature, there is no new matter involved in this presentation.

In view of the foregoing amendments and remarks, reconsideration and allowance of claims 1 and 7, as amended, and claims 2-6, 8, and 9 are requested, as satisfying 35 U.S.C. § 112, second paragraph.

The Rejection under 35 U.S.C. § 103

Applicants' response to these rejections is based upon the fact that the Examiner has recognized that the rejections are based on the Examiner's best understanding of the claims as originally presented and in the light of his rejection of the claims under 35 U.S.C. § 112.

In this context, it is noted that all of the references cited to sustain the various rejections (Goto et al., Sawai et al.) are directed to speed control circuits that have as an element of that control, speed measurement.

For example, Sawai et al. is directed to removing speed measurement as a factor in providing a torque indicating signal. As the Examiner recognized, there is no relationship to a synchronous permanent magnet motor or the concept of accurately measuring the speed of such a motor.

As for Goto et al., it too suffers from the same conceptual deficiencies as Sawai et al. Furthermore, it is directed to a complex speed control system for elevators that entails car vibration suppression, load torque prediction, and other parameters such as car position. There is

no discussion in Goto et al. of treating drift correction, namely, zero and gain error in a speed sensor (such as a tachometer) for measuring the speed of a synchronous permanent magnet motor.

In short, the Goto et al. and Sawai et al. references fail to teach the problem solved by Applicants, much less the solution to that problem. For example, the Examiner's reference to Goto et al. Fig. 9 characterizing item 3 and item 36 (not present in Fig. 9) as an "identifying unit for identifying a gain factor and a zero factor" finds no basis in fact in Goto et al. for this assertion by the Examiner. Here again, Goto et al. is concerned with load torque prediction and its disclosure is askew of Applicants' claimed invention.

Claims 1-9 are not rendered obvious by Goto et al. and/or Sawai et al.

Reconsideration and allowance of claims 1-9, to the extent present amended, are requested.

Conclusion

Should there be any outstanding matters that need to be resolved in the present application, the Examiner is respectfully requested to contact Terrell C. Birch (#19,382) at the telephone number of the undersigned below, to conduct an interview in an effort to expedite prosecution in connection with the present application.

If necessary, the Commissioner is hereby authorized in this, concurrent, and future replies, to charge payment or to credit any overpayment to Deposit Account No. 02-2448 for any additional fees required under 37 C.F.R. § 1.16 or under 37 C.F.R. § 1.17; particularly, extension of time fees.

Dated: October 12, 2006

Respectfully submitted,

By #19382

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Attachments: Appendix A: Definitions from Wikipedia - http://en.wikipedia.ora/wiki/Sensor

Appendix B: Beckemeyer, Heinz-Perete, "Signal Acquisition and Conditioning with Low Supply Voltages," Texas Instruments Deutschland GmbH, June 1996

Application No.: 10/756,380
APPENDIX A to Reply dated October 12, 2006
to Office Action of July 12, 2006

Sensor

From Wikipedia, the free encyclopedia

Distinguish from censure and censer and censor.

Contents

Overview

Most sensors are electrical or electronic, although other types exist. A sensor is a type of transducer. Sensors are either direct indicating (e.g. a mercury thermometer or electrical meter) or are paired with an indicator (perhaps indirectly through an analog to digital converter, a computer and a display) so that the value sensed becomes human readable. In addition to other applications, sensors are heavily used in medicine, industry and robotics. Technical progress allows more and more sensors to be manufactured with MEMS technology. In most cases this offers the potential to reach a much higher sensitivity. See also MEMS sensor generations.

Types

Since a significant change involves an exchange of energy, sensors can be classified according to the type of energy transfer that they detect.

Thermal

- temperature sensors: thermometers, thermocouples, temperature sensitive resistors (thermistors and resistance temperature detectors), bi-metal thermometers and thermostats
- heat sensors: bolometer, calorimeter

Electromagnetic

- electrical resistance sensors: ohmmeter, multimeter
- electrical current sensors: galvanometer, ammeter
- electrical voltage sensors: leaf electroscope, voltmeter
- electrical power sensors: watt-hour meters
- magnetism sensors: magnetic compass, fluxgate compass, magnetometer, Hall effect device,
- metal detectors

Mechanical

- pressure sensors: altimeter, barometer, barograph, pressure gauge, air speed indicator, rate of climb indicator, variometer
- gas and liquid flow sensors: flow sensor, anemometer, flow meter, gas meter, water meter, mass flow sensor
- mechanical sensors: acceleration sensor, position sensor, selsyn, switch, strain gauge

Chemical

Chemical sensors detect the presence of specific chemicals or classes of chemicals. Examples include oxygen sensors, also known as lambda sensors, ion-selective electrodes, pH glass electrodes, and redox electrodes.

Optical and radiation

- electromagnetic time-of-flight. Generate an electromagnetic impulse, broadcast it, then measure the time a reflected pulse takes to return. Commonly known as - RADAR (**Ra**dio **D**etection **A**nd **R**anging) are now accompanied by the analogous LIDAR (**Li**ght **D**etection **A**nd **R**anging. See following line), all being electromagnetic waves. Acoustic sensors are a special case in that a pressure transducer is used to generate a compression wave in a fluid medium (air or water)
- light time-of-flight. Used in modern surveying equipment, a short pulse of light is emitted and returned by a retroreflector. The return time of the pulse is proportional to the distance and is related to atmospheric density in a predictable way.

Ionising radiation

- radiation sensors: Geiger counter, dosimeter, Scintillation counter, Neutron detection
- subatomic particle sensors: Particle detector, scintillator, Wire chamber, cloud chamber, bubble chamber. See Category:Particle_detectors

Non-ionising radiation

- light sensors, or *photodetectors*, including semiconductor devices such as photocells, photodiodes, phototransistors, CCDs, and Image sensors; vacuum tube devices like photo-electric tubes, photomultiplier tubes; and mechanical instruments such as the Nichols radiometer.
- infra-red sensor, especially used as occupancy sensor for lighting and environmental controls.
- proximity sensor- A type of distance sensor but less sophisticated. Only detects a specific proximity. May be optical - combination of a photocell and LED or laser. Applications in cell phones, paper detector in photocopiers, auto power standby/shutdown mode in notebooks and other devices. May employ a magnet and a Hall effect device.
- scanning laser- A narrow beam of laser light is scanned over the scene by a mirror. A photocell sensor located at an offset responds when the beam is reflected from an object to the sensor, whence the distance is calculated by triangulation.
- focus. A large aperture lens may be focused by a servo system. The distance to an in-focus scene element may be determined by the lens setting.
- binocular. Two images gathered on a known baseline are brought into coincidence by a system of mirrors and prisms. The adjustment is used to determine distance. Used in some cameras (called range-finder cameras) and on a larger scale in early battleship range-finder
- interferometry. Interference *fringes* between transmitted and reflected lightwaves produced by a coherent source such as a laser are counted and the distance is calculated. Capable of extremely high precision.
- Scintillometers measure atmospheric optical disturbances.

Acoustic

- sound sensors: microphones, hydrophones, seismometers.

acoustic: uses ultrasound time-of-flight echo return. Used in mid 20th century polaroid cameras and applied also to robotics. Even older systems like Fathometers (and fish finders) and other 'Tactical Active' Sonar (**S**ound **N**avigation **A**nd **R**anging) systems in naval applications which mostly use audible sound frequencies.

Other types

- motion sensors: radar gun, speedometer, tachometer, odometer, occupancy sensor, turn coordinator
- orientation sensors: gyroscope, artificial horizon, ring laser gyroscope
- distance sensor (noncontacting) Several technologies can be applied to sense distance: magnetostriction

Non Initialized systems

- Gray code strip or wheel- a number of photodetectors can sense a pattern, creating a binary number. The gray code is a mutated pattern that ensures that only one bit of information changes with each measured step, thus avoiding ambiguities.

Initialized systems

These require starting from a known distance and accumulate incremental changes in measurements.

- Quadrature wheel- An disk-shaped optical mask is driven by a gear train. Two photocells detecting light passing through the mask can determine a partial revolution of the mask and the direction of that rotation.
- whisker sensor- A type of touch sensor and proximity sensor.

Classification of measurement errors

A good sensor obeys the following rules:

1. the sensor should be sensitive to the measured property
2. the sensor should be insensitive to any other property
3. the sensor should not influence the measured property

In the ideal situation, the output signal of a sensor is exactly proportional to the value of the measured property. The gain is then defined as the ratio between output signal and measured property. For example, if a sensor measures temperature and has a voltage output, the gain is a constant with the unit [V/K].

If the sensor is not ideal, several types of deviations can be observed:

- The gain may in practice differ from the value specified. This is called a **gain error**.
- Since the range of the output signal is always limited, the output signal will eventually clip when the measured property exceeds the limits. The **full scale range** defines the outmost values of the measured property where the sensor errors are within the specified range.
- If the output signal is not zero when the measured property is zero, the sensor has an **offset** or **bias**. This is defined as the output of the sensor at zero input.
- If the gain is not constant, this is called **nonlinearity**. Usually this is defined by the amount the output differs from ideal behaviour over the full range of the sensor, often noted as a percentage of the full range.
- If the deviation is caused by a rapid change of the measured property over time, there is a **dynamic error**. Often, this behaviour is described with a bode plot showing gain error and phase shift as function of the frequency of a periodic input signal.
- If the output signal slowly changes independent of the measured property, this is defined as **drift**.

- **Long term drift** usually indicates a slow degradation of sensor properties over a long period of time.
- **Noise** is a random deviation of the signal that varies in time.
- **Hysteresis** is an error caused by the fact that the sensor not instantly follows the change of the property being measured, and therefore involves the history of the measured property.
- If the sensor has a digital output, the signal is discrete and is essentially an approximation of the measured property. The approximation error is also called **digitization error**.
- If the signal is monitored digitally, limitation of the sampling frequency also causes a dynamic error.
- The sensor may to some extent be sensitive for other properties than the property being measured. For example, most sensors are influenced by the temperature of their environment.

All these deviations can be classified as systematic errors or random errors. Systematic errors can sometimes be compensated for by means of some kind of calibration strategy. Noise is a random error that can be reduced by signal processing, such as filtering, usually at the expense of the dynamic behaviour of the sensor.

Resolution

The *resolution* of a sensor is the smallest change it can detect in the quantity that it is measuring. Often in a digital display, the least significant digit will fluctuate, indicating that changes of that magnitude are only just resolved. The resolution is related to the precision with which the measurement is made. For example, a scanning probe (a fine tip near a surface collects an electron tunnelling current) can resolve atoms and molecules.

Biological

All living organisms contain biological sensors with functions similar to those of the mechanical devices described. Most of these are specialized cells that are sensitive to:

- light, motion, temperature, magnetic fields, gravity, humidity, vibration, pressure, electrical fields, sound, and other physical aspects of the external environment;
- physical aspects of the internal environment, such as stretch, motion of the organism, and position of appendages (proprioception);
- an enormous array of environmental molecules, including toxins, nutrients, and pheromones;
- many aspects of the internal metabolic milieu, such as glucose level, oxygen level, or osmolality;
- an equally varied range of internal signal molecules, such as hormones, neurotransmitters, and cytokines;
- and even the differences between proteins of the organism itself and of the environment or alien creatures.

Artificial sensors that mimic biological sensors by using a biological sensitive component, are called biosensors.

The human senses are examples of specialized neuronal sensors. See Sense.

See also

- Actuator
- Data acquisition
- Data acquisition system
- Data logger
- Detection theory
- Hydrogen microsensor
- Lateral line
- Limen
- List of sensors
- Machine olfaction
- Receiver operating characteristic
- Sensor network

External links

- Type of sensors and their working (http://www.articles.co.nr/report/sensors.htm)
- Tutorial on interpreting and analyzing recorded sensor data (http://www.societyofrobots.com/sensors_interpret.shtml)

- SensorWiki (http://sensorwiki.org/) - Sensor information tailored for music technologists.
- Federal Standard 1037C, August 7, 1996: transducer (http://www.its.bldrdoc.gov/fs-1037/dir-032/_4770.htm)
- American National Standard for Telecommunications - Telecom Glossary 2000: sensor (http://www.atis.org/tg2k/_sensor.html)
- SensEdu; how sensors work (http://www.sensedu.com/)
- "Overview of Sensors and Needs for Environmental Monitoring" Clifford K. Ho, Alex Robinson, David R. Miller and Mary J. Davis *Sensors* 2005, **5**, 4-37 [1] (http://www.mdpi.net/sensors/papers/s5010004.pdf) (open access) article
- The art of detection: UGS systems make a quantum leap in reliability and utility (http://www.janes.com/defence/land_forces/news/idr/idr060803_1_n.shtml) International Defence Review, 3 August 2006

Categories: Cleanup from September 2006 | Measuring instruments | Sensors

Application No.: 10/756,380
APPENDIX B to Reply dated October 12, 2006
to Office Action of July 12, 2006

Signal Acquisition and Conditioning with Low Supply Voltages

Heinz-Peter Beckemeyer
Texas Instruments Deutschland GmbH

June 1996

TEXAS INSTRUMENTS

Contents

List of Figures

1. INTRODUCTION

Digital systems are being ever-increasingly used for measurement and control applications. However, all the variables in the "real world" which sensors are used to measure (such as temperature, pressure or light intensity) are analog in their physical nature: an element is therefore always needed to link the analog environment to the digital system. This usually also means that signals from sensors must be appropriately modified, such that they are made suitable for conversion into a digital data format.

This Application Report discusses in detail a pressure sensor circuit, such as for example could be used in under-water diving equipment, or in a device to measure altitude. The details of the circuits are described for the measurement of the pressure, for the temperature measurement which is thereby required, and also the circuitry for interfacing the analog-digital converter to the microcomputer.

In addition, this Report shows how a measurement system can be constructed which operates on a supply voltage of only 3 Volts. The operation of sensors from a 3-Volt supply is particularly useful in portable systems, in order to allow the longest possible operation time. At the same time, it is desirable that a level of performance should be achievable which is as good as that of systems operating on higher supply voltages. This can present a challenge with 3-Volt sensor systems. The data acquisition system of the application discussed in this Report, which was constructed using the 10-bit analog-digital converter TLV1543 and used in conjunction with two different microcomputers, attained a resolution of 10 bit and a precision of 9 bit.

2. 3-V SUPPLY VOLTAGE

Many current electronic systems operate from a supply voltage of 5 Volts. This is the result of the significant influence of the SN74 families of logic, which operate from 5 Volts, and the widespread use made of these logic families in the computer industry. The strongly increasing demand for improvements in the characteristics and performance of portable electronic equipment has obliged the manufacturers of integrated circuits to develop completely new families of components which fulfill the requirements of such applications. The principle feature of these components should be that, given a certain quantity of energy, they should be capable of operating for a long period of time. The best way of achieving this is with a reduction in the operating voltage that they require. In order to attain adequate power savings, an operating voltage of 3 Volts was chosen, without having to accept any significant compromise in performance.

2.1 Signal Processing Limitations

The high immunity to noise of digital signals is one of the most important advantages which they provide, when compared with analog signals. This aspect is decisive in ensuring that the performance of digital circuits, when operated with a reduction of the supply voltage to 3.3 Volts, shall not be adversely affected to any significance. Components containing linear functions (such as operational amplifiers and analog-digital converters) are significantly more sensitive to the effects of noise.

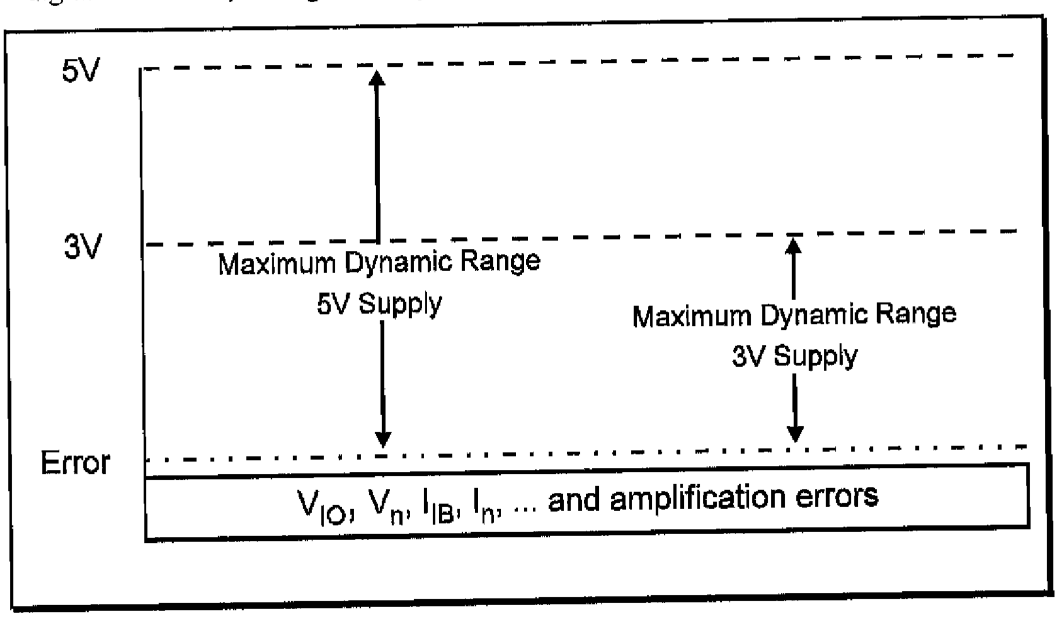

Figure 2.1: The dependence of dynamic range on supply voltage

The dynamic range of an operational amplifier which is operated from a single supply voltage has an upper limit determined by the magnitude of the positive supply voltage, and a lower limit imposed by the sum of all the errors present in the operational amplifier. A reduction of the supply voltage thus reduces the maximum attainable dynamic range of the control signal, and thus the overall performance.

Figure 2.1 shows how the dynamic range of a typical linear component is reduced when the supply voltage is only 3 Volts instead of 5 Volts. A reduction of the supply voltage from 5 Volts to 3 Volts is equivalent to a reduction in the dynamic range of 4 - 5 dB.

For this reason, it is particularly important that as much as possible of the reduced supply voltage remains available for the control range. This can be achieved by making use of components which can be driven up to the limits ("Rail-to-Rail") of their supply voltage. Texas Instruments offers an increasing number of such Rail-to-Rail operational amplifiers in Advanced LinCMOS technology, for both 5-Volt and 3-Volt systems.

An additional problem is that operational amplifiers of particularly high DC precision (e.g. chopper operational amplifiers, of which the input offset voltage VIO is about 1 µV) are not available for operation with a single 3-Volt supply voltage. In order therefore to achieve sufficient precision, the errors of all the components used are calibrated together. An explanation of this approach is given in the next section.

Based on these requirements, components from the TLV 'Low Voltage' series are used for the application on question. These components were specially developed for operation with low supply voltages.

In particular, the operational amplifier TLV2262 was used. This can be supplied from a single supply voltage, and operated up to the limits of that supply voltage. The TLV2262 is ideally suitable for portable applications, because it has a current consumption of only 200 µA per channel at an operating voltage of 3 Volts. In addition, care must be taken in this application that the operational amplifiers do not present too much of a load on the pressure sensor. The TLV2262 is suitable in this case, because, like many other CMOS operational amplifiers, it has PMOS transistors in the input stage, which ensure that the input resistance is extremely high.

The TLV1543 is used as the A/D converter; this also operates with a single supply voltage. The TLV1543 is provided with 11 analog input channels. The integrated input changeover switch makes these converters particularly suitable for use in this sensor application. The amplified sensor signal is taken via one input channel to the A/D converter, and the temperature signal via the other. A detailed description of the TLV1543 follows in Section 6.2.

3. CIRCUIT DESCRIPTION

The circuit used for pressure measurement can be seen in Figure 3.. The pressure sensor used (type number: Sensym SX05) operates on a piezo-resistive basis. It consists of four piezo-resistive resistors, which are connected together electrically in such a way that they form a Wheatstone bridge. The operating voltage is applied to one of the bridge diagonals, and - depending on the applied pressure - a potential difference appears across the second bridge diagonal which is a measure of the applied pressure. This signal is applied directly to the input of a differential amplifier. This differential amplifier consists of the operational amplifier TLV2262 and the resistance network which sets the amplification. The capacitor C1 has in this case the function of a low-pass filter. In this way, interference from high-frequency components is suppressed.

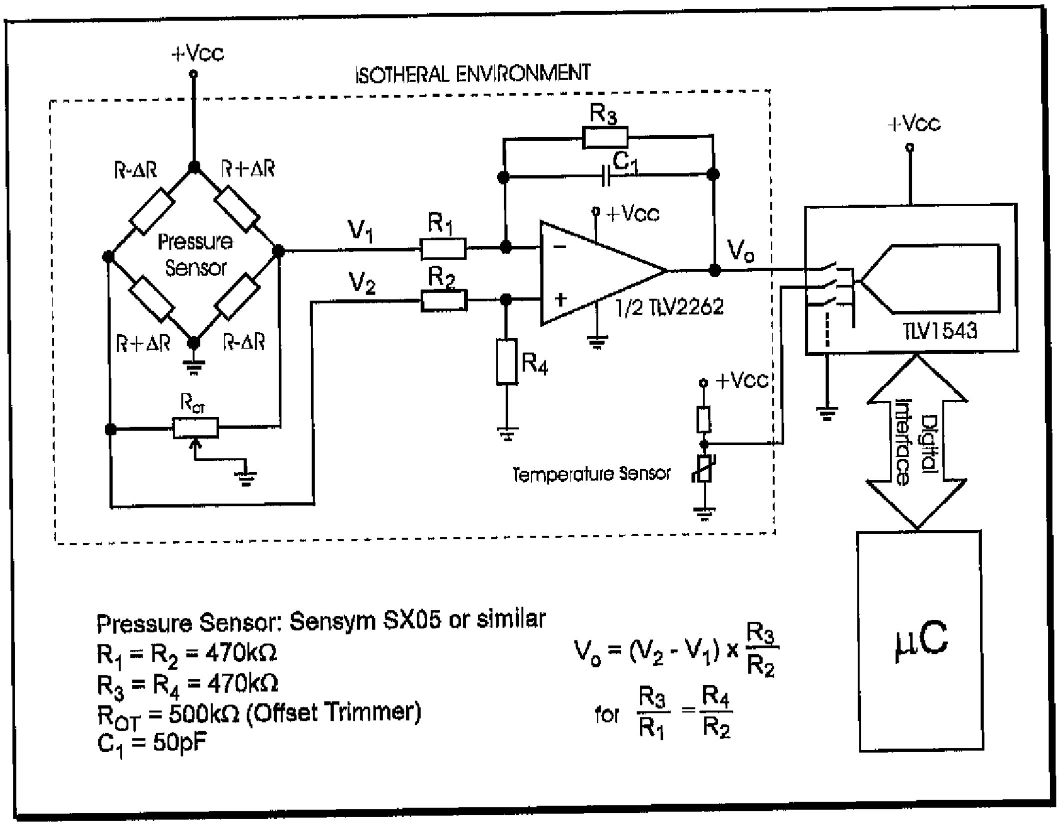

Figure 3.1: Circuit diagram for the measurement of pressure

As already mentioned, the operational amplifier is operated with a single supply voltage: this means that it can only be driven into a positive region. As a result of the polarity of the pressure sensor offset voltage, and because of the limited region into which the operational amplifier can be driven, the offset voltage of this pressure sensor must be shifted by means of the potentiometer R_{OT} to ensure that the operational amplifier is not overloaded.

The output signal of the operational amplifier is taken to the 10-bit A/D converter TLV1543. A microcomputer controls both the A/D conversion and the serial output of the A/D converter. The result of the A/D conversion which is read into it is

evaluated by the microcomputer. In addition, for each pressure measurement the ambient temperature must be measured. This is done by means of a temperature sensor, which has a linearization resistor in series with it. The temperature signal which is sensed is passed to one of the free channels of the TLV1543. A detailed description of the method by which the temperature is measured follows in Section 5, Temperature Measurement.

An unusual aspect of this application is that the circuit, consisting of the sensor and the operational amplifier, can be considered as a closed system - in other words, as a "Black Box". This has the advantage that the sources of error which result from the sensor (e.g. temperature coefficient of the offset and of the bridge resistors) and from the operational amplifiers (e.g. the input offset voltage, the input offset current, and the temperature coefficients) do not need to be considered individually. Absolute accuracy of the sensor and the operational amplifier is not needed - only relative accuracy is required. As already explained in Section 2.1, it is important that it should be possible to drive the operational amplifier up to the supply voltage (Rail-to-Rail), so that the maximum dynamic range can be achieved. It is however absolutely necessary that the complete circuit consisting of the sensor and operational amplifier be subjected to the same temperature conditions. This part of the circuit is shown enclosed in dotted lines in Figure 3., and is demarcated as an isothermal environment.

After construction of the circuit, calibration of the complete system must be undertaken, as described in detail in Section 4.

4. SYSTEM CALIBRATION

The system has two significant sources of potential errors, which must both be compensated whenever a pressure measurement is undertaken. These errors are the temperature-dependent system offset voltage, and the system amplification which is also temperature-dependent. In order to be able to compensate for these errors, the behavior of the offset voltage and of the amplification as a function of the temperature and pressure must be examined in more detail.

4.1 Characteristics of the System

The complete circuit provides characteristics which are to a large extent linear at constant temperature, as can be seen in Figure 4.1.

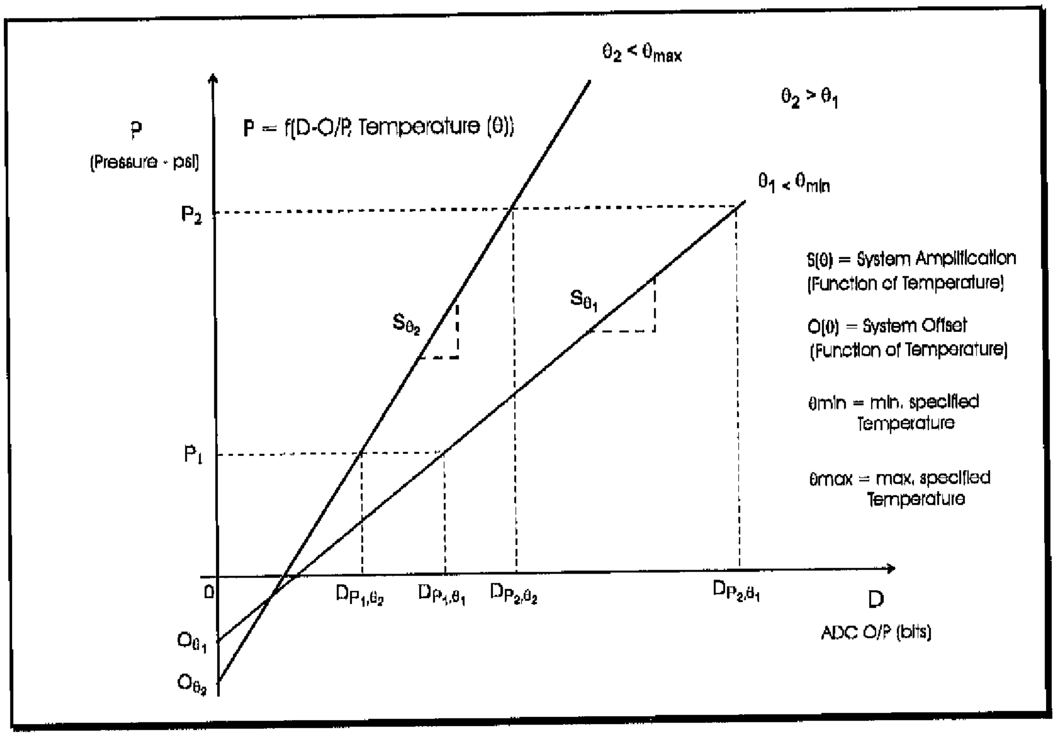

Figure 4.1: Characteristics of the system

The pressure P is shown as the ordinate of the coordinate systems, and the digital value of the A/D converter as the abscissa. It will be observed that, with a constant temperature θ, a linear characteristic having a system slope S(θ) and an offset value of O(θ) (the intersection with the ordinate) results. These characteristics can be described mathematically with a straight-line relationship as follows:

$$P = D \times S(\theta) + O(\theta)$$

The system slope S(θ) and the offset value O(θ) are in this case dependent on the instantaneous ambient temperature, and it will now be necessary to deduce these dependencies.

4.2 Slope and Offset Behavior

The temperature coefficients of the system slope, and of the system offset, were established by means of several measurements, for which a precise and stable arrangement of the pressure and temperature measuring equipment was necessary. Figure 4.2 shows the system slope (amplification) as a function of the ambient temperature.

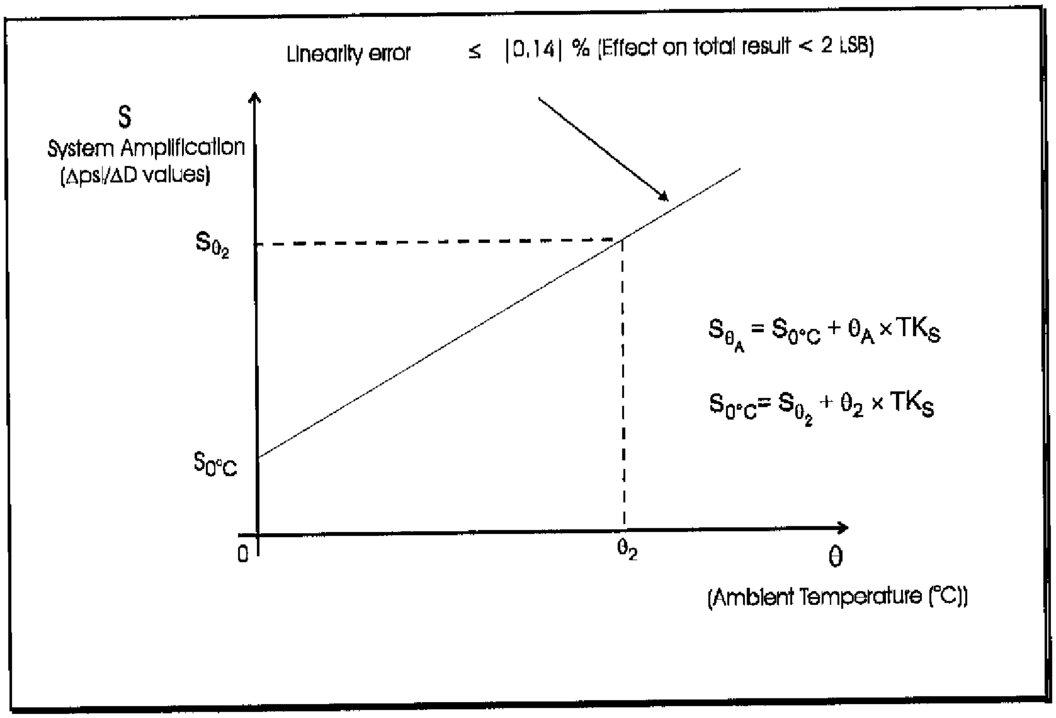

Figure 4.2: System slope as a function of temperature

These measurements have shown that the characteristics are linear to a close approximation. The actual linearity error was found to be £ |0.14| %. The effect of this on the overall precision of the circuit is thus less than 2 LSB, and it is therefore permissible to consider the behavior of the system amplification as a function of temperature as having a straight-line characteristic, as can be seen in Figure 4.2.

The system offset, as a function of temperature, also shows similar behavior. It again demonstrates largely linear characteristics, with a linearity error of £ |0.5| %; the effect on the overall performance in this case is less than 1/2 LSB. Again, a straight-line characteristic can also be assumed for the behavior the system offset as a function of temperature.

Figure 4.3 shows the system offset as a function of the temperature.

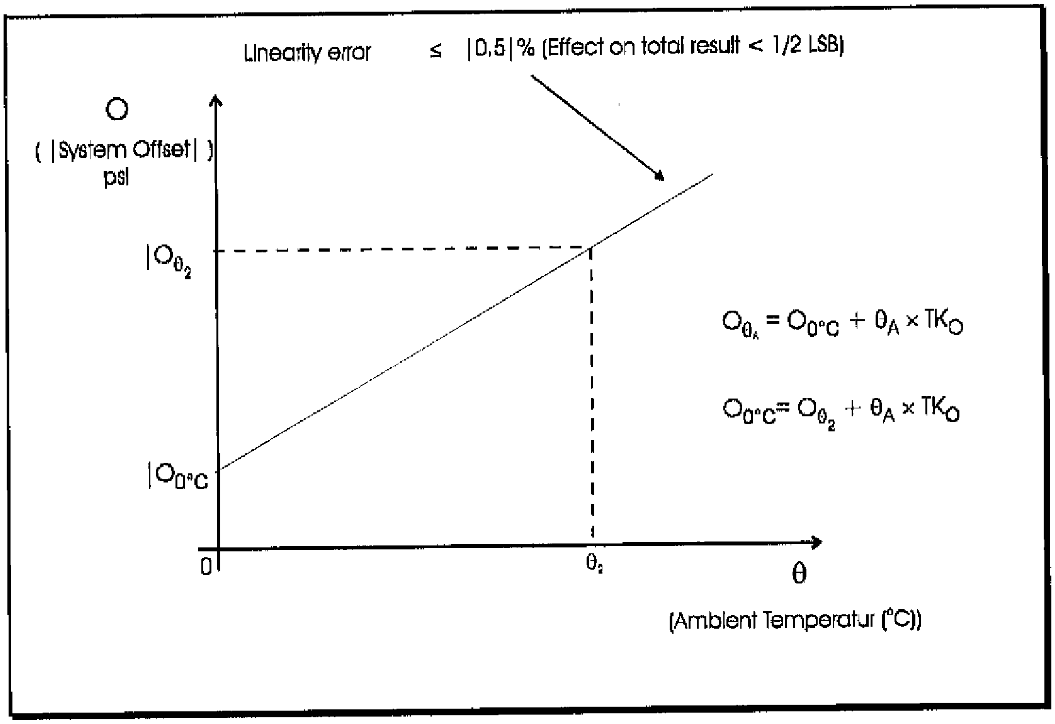

Figure 4.3: System offset as a function of temperature

4.3 Derivation of the System Formula

The equations which have been derived for the system slope and for the system offset can now be incorporated in an equation for the output, in order to derive the formula which is valid for the complete system. The derivation of this system formula will now be briefly presented.

Equation for the linear characteristic:	$P = D ' S(q) + O(q)$	[1]
System slope as a function of the temperature:	$S(q) = S_{0°C} + q_A ' TK_S$	[2]
System offset as a function of the temperature:	$O(q) = O_{0°C} + q_A ' TK_O$	[3]

By inserting the equations [2] and [3] in the output equation [1], the applicable system formula [4] is obtained.

System formula: $\boxed{P = D ' (S_{0°C} + q_A ' TK_S) + O_{0°C} + q_A ' TK_O}$ [4]

The meaning of the individual parameters in these expressions is as follows:

P	=	Actually applied pressure
D	=	Digital value of output of the A/D converter
$O_{0°C}$	=	System offset at 0°C
O_θ	=	System offset at temperature θ
$S_{0°C}$	=	System slope at 0°C
S_θ	=	System slope at temperature θ
θ_A	=	Ambient temperature
TK_O	=	System offset temperature coefficient
TK_S	=	System slope temperature coefficient

After the digital pressure and value of the temperature have been read into the microcomputer, the latter can now use the system formula to determine the actual pressure.

4.4 Calibration Formulae

In order to calibrate a pressure measurement system of this kind, it is now necessary to determine the parameters described above. For this purpose it is sufficient to record four measurement points on two of the curves, as shown in Figure 4.1. With the help of these four measurement points, the complete pressure measurement system can be calibrated. These calibration formulae will now be presented below.

4.4.1 Calculation of the Slope Parameters

Slope S_{θ_1} of the characteristic:

$$S_{\theta_1} = \frac{P_2 - P_1}{D_{P_2,\theta_1} - D_{P_1,\theta_1}} \quad [5]$$

Slope S_{θ_2} of the characteristic:

$$S_{\theta_2} = \frac{P_2 - P_1}{D_{P_2,\theta_2} - D_{P_1,\theta_2}} \quad [6]$$

Temperature coefficient TK_S of the slope:

$$TK_S = \frac{S_{\theta_2} - S_{\theta_1}}{\theta_2 - \theta_1} \quad [7]$$

Slope S at 0°C:

$$S_{0°C} = S_{\theta_2} - TK_S \quad [8]$$

4.4.2 Calculation of the Offset Parameters

Offset O_{θ_1} of the curve: $$O_{\theta_1} = P_2 - D_{P_2,\theta_1} \times S_{\theta_1} \quad [9]$$

Offset O_{θ_2} of the curve: $$O_{\theta_2} = P_2 - D_{P_2,\theta_2} \times S_{\theta_1} \quad [10]$$

Temperature coefficient TK_O of the offset: $$TK_O = \frac{O_{\theta_2} - O_{\theta_1}}{\theta_2 - \theta_1} \quad [11]$$

Offset O at 0°C: $$S_{0°C} = S_{\theta_2} - TK_S \quad [12]$$

The parameter which have been calculated are now stored in the microcomputer, and extracted for each calculation.

5. TEMPERATURE MEASUREMENT

As already mentioned, a measurement of the ambient temperature is necessary for every pressure measurement, in order to be able to compensate for the effects of temperature on the circuit. In this application, the ambient temperature is measured with the use of a silicon temperature measurement sensor from Philips, type KTY81-150. The ohmic resistance of this sensor changes in accordance with the temperature.

5.1 Linearization of the Sensor

Most temperature sensors have non-linear characteristic, which must therefore be linearized. The characteristics of the resistance of the temperature measurement sensor used in this application are shown in Figure 5.1, as a function of the temperature.

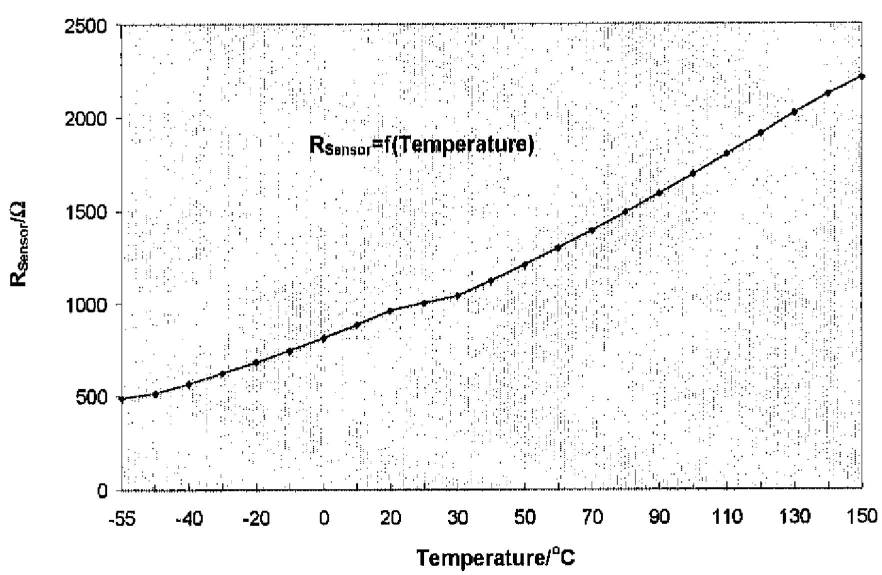

Figure 5.1: Characteristics of the temperature sensor

The characteristics of the temperature sensor can be linearized in various different ways. If the circuit is fed from a constant current source, a linearization resistor can be connected in parallel with the sensor, as shown in Figure 5.2(a). If the circuit is fed from a constant voltage source, then a linearization resistor can be connected in series with the sensor. This method of linearization is shown in Figure 5.2 (b). The signal which is taken from the temperature sensor ($V_{A/D}$) is applied directly to one of the free channels of the A/D converter TLV1543. The microcomputer is now able to evaluate the digitized value of the temperature.

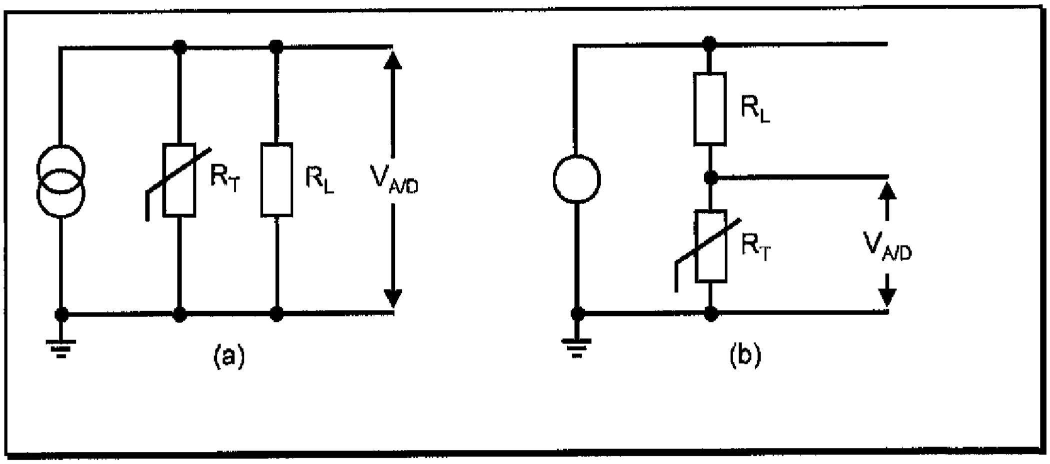

Figure 5.2: Temperature sensor linearization

The actual value of the linearization resistor depends on the desired range of temperature over which the circuit should be operated. The linearization resistance value is calculated using formula [13]:

$$R_L = \frac{R_M \times (R_1 + R_2) - 2 \times R_1 \times R_2}{R_1 + R_2 - 2 \times R_M} \qquad [13]$$

where:

R_1 = Sensor resistance at minimum temperature
R_2 = Sensor resistance at maximum temperature
R_M = Sensor resistance at the average temperature

The linearization resistor reduces the linearity error to $< \pm 0.15°C$. This represents an error of much less than 1/2 LSB for the complete system.

5.2 Sensor Calibration

After the linearization procedure, the calibration of the temperature sensor can now be performed. Starting from the characteristics of the temperature sensor circuit, a calibration formula for the microcomputer can be derived. The characteristic of the circuit which represents the behavior of the digital value of the output as a function of the ambient temperature θ_A, is shown in Figure 5.3. Since in this case we have a straight-line characteristic, it is sufficient to determine two points on the characteristic curve, as shown in Figure 5.3, in order to determine the value of this linear expression.

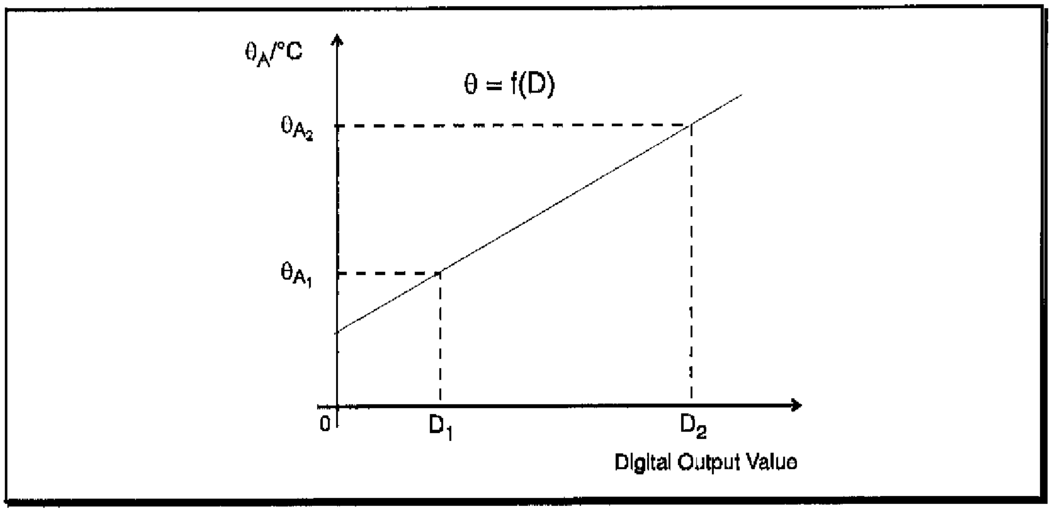

Figure 5.3: The digital value of the output as a function of the temperature

The linear expression for this characteristic is as follows:

$$\theta = D \times S_\theta + O_\theta \quad [14]$$

where:

θ	=	Correct temperature
D	=	A/D conversion value of the temperature measurement
S_θ	=	Calibration parameter for the slope of the curve
O_θ	=	Calibration parameter for the offset of the curve

The calculation of the parameters S_θ and O_θ is in this case performed using the formulae [15] and [16].

$$S_\theta = \frac{\theta_{A_2} - \theta_{A_1}}{D_2 - D_1} \quad [15]$$

$$O_\theta = \theta_{A_2} - D_2 \times S_\theta \quad [16]$$

where:

θ_{A_1}	=	Ambient temperature 1
θ_{A_2}	=	Ambient temperature 2
D_1	=	A/D conversion value of the ambient temperature 1
D_2	=	A/D conversion value of the ambient temperature 2

For calculating these parameters, the following must apply: $\theta_{A_1} < \theta_{A_2}$

With the help of these parameters and of the linear expression [14], the microcomputer is now able to calculate the exact value of the temperature using the results of the A/D conversion. This temperature value is needed in the system formula for the calculation of the actual pressure.

6. INTERFACES

6.1 Introduction to Interfaces

This section of the Application Report describes how an interface can be constructed from the TLV1543 to the microcomputers TMS70C42 and MC68B11. The microcomputer TMS70C42 from Texas Instruments and the microcomputer MC68B11 from Motorola were chosen because they can both be operated with a supply voltage of 3.3 Volts. There now follows a detailed description of the A/D converter TLV1543.

6.2 The A/D Converter TLV1543

The TLV1543 is a 10-bit A/D converter which is specified for operation from a single supply voltage of 3.3 Volts, and which has 11 analog input channels and a serial output channel. This A/D converter uses the successive approximation principle for conversion and has capacitors in binary steps, with which a maximum conversion time of 21 µs can be achieved. The serial interface to the higher level microcomputer consists of five lines: namely, the I/O clock, chip select, address input, data output and the quit signal EOC (End of Conversion).

The functional block circuit diagram of the TLV1543 is shown in Figure 6.1. The converter contains a 14-channel multiplexer. Of these 14 channels, 11 are used for the analog inputs. Three further channels can be employed for a self test. In this way, the functionality of the A/D converter can be tested. This operating mode can be used later for tests on the complete system. The multiplexer is followed by a sample-and-hold stage. The voltage stored at this point is now taken to a 12-bit converter. The converted data is read into a data register, and converted from parallel into serial form. The multiplexer is controlled via the input address register. The individual functional blocks of the converter are controlled via control logic. After the completion of a conversion cycle, the converter outputs an EOC signal.

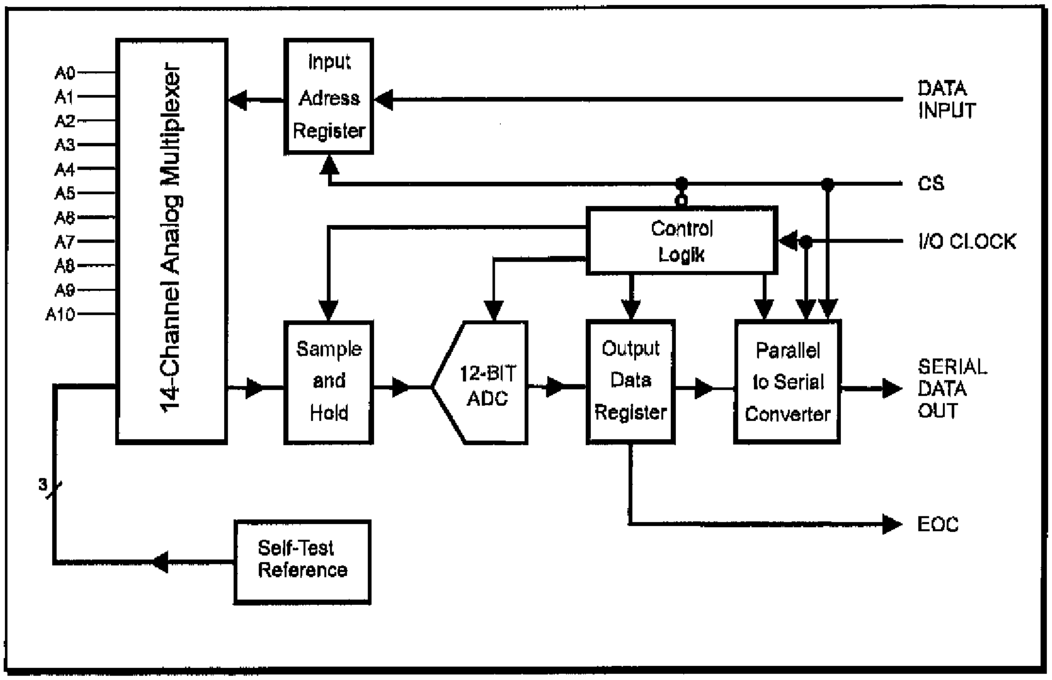

Figure 6.1: Functional block diagram of the TLV1543

6.3 Interface of TLV1543 to TMS70C42

In this section, the interface of the TLV1543 to the microcomputer TMS70C42 will be described in more detail. The circuit can be seen in Figure 6.2. The interface between the A/D converter and the microcomputer is formed by three inputs/outputs of the Port A, and by one input of the Port B. The programming of the direction of data flow from Port A is undertaken by the internal 'Port A Direction Register' (ADDR). In this microcomputer, Port B is exclusively an output register.

The positive reference voltage of the A/D converter is connected directly to the supply voltage, and the negative reference voltage directly to the ground connection GND.

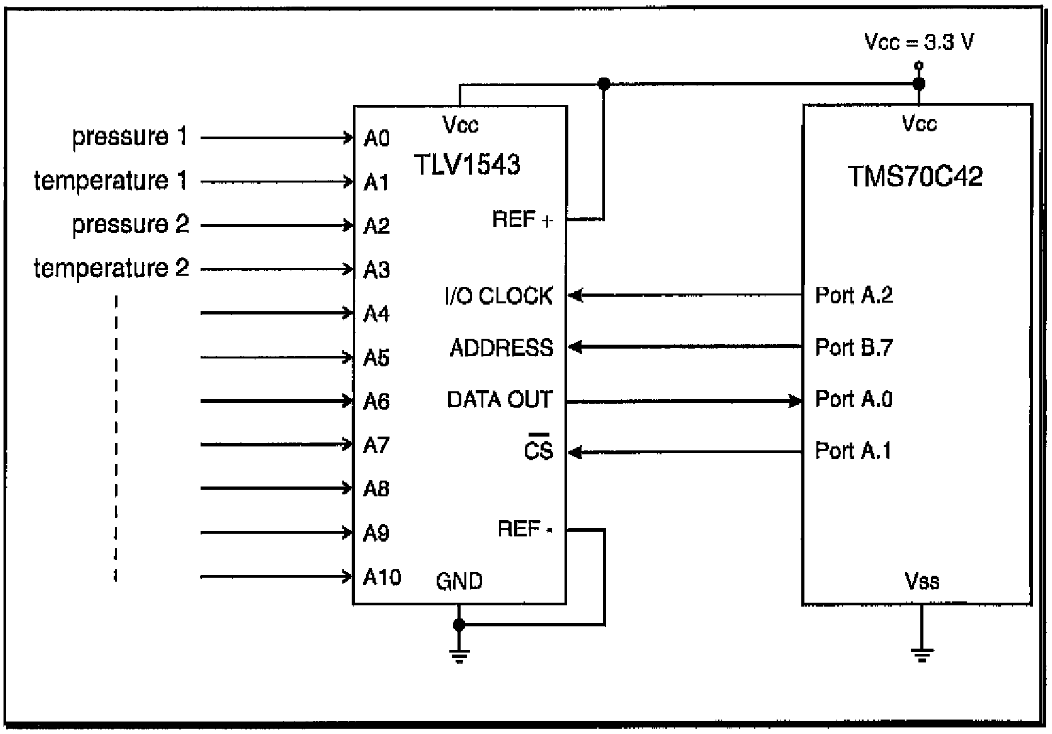

Figure 6.2: Interface of TLV1543 to TMS70C42

6.3.1 TLV1543 Chip Select Signal

The signal for Chip Select is controlled by Bit 1 from Port A. For this purpose, the bi-directional Port A.1 must be programmed as an output, so that this signal can be set by the microcomputer to a 0, or to a 1. When performing the programming care must be taken that the High level is maintained for at least 21 µs. This time can be assured by means of an appropriate delay loop.

6.3.2 TLV1543 Clock Signal

The clock signal needed for the TLV1543 is generated by Port A.2. For this to be done, the bi-directional Port A.2 must also be programmed as an output. The generation of the clock signal is performed by the program, as can also be seen in the program list 1.

6.3.3 TLV1543 Address Data

The address data needed by the A/D converter is transmitted via the unidirectional Port B.7, and this gives information regarding the channel of the converter which must be converted.

6.3.4 TLV1543 Data Output Stream

The results of the A/D conversion can be read from Port A, Bit 0. For this purpose, the bi-directional Port A.0 must be programmed as an input. The ten data bits,

controlled by two program loops, are read into the registers R10 and R11. From this point, the data can be further processed.

Figure 6.3 shows the pulse timing diagram for a 10-bit transfer making use of the signal $\overline{CS}$.

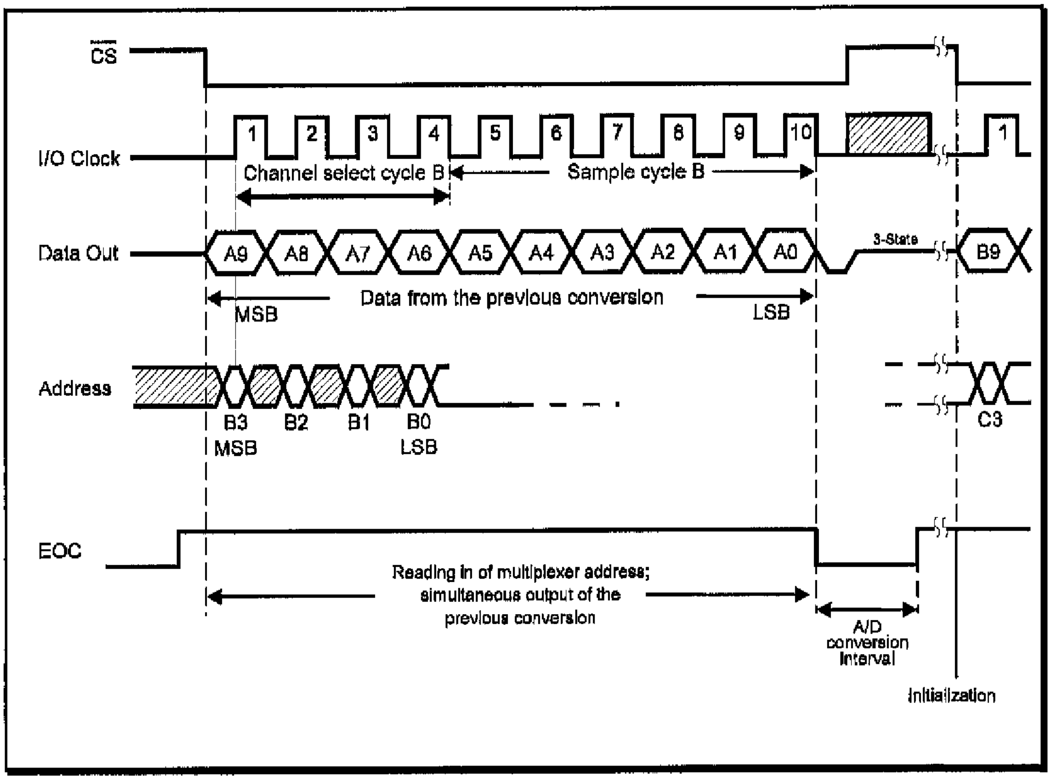

Figure 6.3: Timing behavior of the TLV1543 and TMS70C42

6.3.5 The program of the TMS70C42

The program for controlling the interface between the TLV1543 and the TMS70C42, as shown in Figure 6.2, can be seen in the Program List 1. This program example shows how the analog/digital converter TLV1543 is controlled by the microcomputer TMS70C42, and how the results of a conversion can be read out.

```
*************************************************************
*                TLV1543 - TMS70C42 Interface Program       *
*                                                           *
* This program shows an example of how the functions of the *
* TLV1543 A/D Converter can be controlled via the Port A and*
* Port B (A0, A1, A2 and B7)of the microcomputer, and how   *
* the conversion results can be read out.                   *
*************************************************************

0000
0004  APORT    EQU    P4          * * * * * * * * * * * * * *
0005  ADDR     EQU    P5          * Name of the register    *
0006  BPORT    EQU    P6          * * * * * * * * * * * * * *
F006  AORG     >F006              Load start address of
F006  52 INIT  MOV    %>60,B      program 60h in B register
F007
F008  0D       LDSP               Load pointer to stack
F009  72       MOV    %>02,R4     Load control variable
F00A  02
F00B  04
F00C  A2       MOVP   %>06,ADDR   Data flow from Port A
F00D  06
F00E  05
F00F  72 LOOP1 MOV    %>00,R10    R10 for converted data
F010  00
F011  0A
F012  72       MOV    %>00,R11    R11 for converted data
F013  00
F014  0B
F015   A2      MOVP   %>20,BPORT  Setting of the ADC channel
F016  20
F017  06
F018  A4       ORP    %>02,APORT  Set CS from Low to High
F019  02
F01A  04
F01B  A3       ANDP   %>FD,APORT  Set CS from High to Low
F01C  FD
F01D  04
F01E  72       MOV    %>08,R2     Set control variable
F01F  08
F020  02
F021  72       MOV    %>02,R3     Set control variable
F022  02
F023  03
F024  91 LOOP2 MOVP   APORT,B     PORT A (Bit A0 contains)
F025  04
F026  CD       RRC    B           Load data bit in CARRY FLAG
```

```
0030 F027  DF         RLC    R10         and thence into Register 10
     F028  0A
0031 F029  D2         DEC    R2          Decrement R2
     F02A  02
0032 F02B  A4         ORP    %>04,APORT Clock from Low to High
     F02C  04
     F02D  04
0033 F02E  A3         ANDP   %>FB,APORT Clock from High to Low
     F02F  FB
     F030  04
0034 F031  91         MOVP   BPORT,B     Channel address into
     F032  06                            REGISTER B
0035 F033  CE         RL     B           Shift left
0036 F034  92         MOVP   B,BPORT     Channel address to PORT B
     F035  06
0037 F036  76         BTJO   %>FF,R2,LOOP2 Query if R2=0
     F037  FF
     F038  02
     F039  EA
0038 F03A  91 LOOP3   MOVP   APORT,B     PORT B to Register B
     F03B  04
0039 F03C  CD         RRC    B          Load data bit into CARRY FLAG
0040 F03D  DF         RLC    R11        and from there to Register 10
     F03E  0B
0041 F03F  D2         DEC    R3          Decrement R3
     F040  03
0042 F041  A4         ORP    %>04,APORT Clock from Low to High
     F042  04
     F043  04
0043 F044  A3         ANDP   %>FB,APORT Clock from High to Low
     F045  FB
     F046  04
0044 F047  76         BTJO   %>FF,R3,LOOP3 Query if R3=0
     F048  FF
     F049  03
     F04A  EF
0045 F04B  A4         ORP    %>02,APORT PORT B to Register B
     F04C  02
     F04D  04
0046 F04E  D2         DEC    R4
     F04F  04
0047 F050  76         BTJO   %>FF,R4,LOOP1 Query if R4=0
     F051  FF
     F052  04
     F053  BB
0048                  END
```

Program List 1

In Table 1 is shown which address must be loaded into the BPORT register, in order to select the desired input of the multiplexer.

Channel Table	
Analog Input	Hex Address
A0	00
A1	10
A2	20
A3	30
A4	40
A5	50
A6	60
A7	70
A8	80
A9	90
A10	A0

Table 1: Channel Table

In Table 2 is shown how the BPORT register must be loaded in order to set a test function for the A/D converter. In addition, this table gives the digital value of the output for each test function. In this case, V_{ref+} is the voltage which appears at the Ref+ input of the A/D converter, and V_{ref-} is the voltage appearing at the A/D converter Ref- input.

Test Input	Hex Address	Hex Output Value
$\frac{V_{ref+} - V_{ref-}}{2}$	B0	200
V_{ref+}	C0	000
V_{ref-}	D0	3FF

Table 2: Test Input Table

6.4 Interface of TLV1543 to MC68B11

By far the most effective method of controlling the mode and data flow of the TLV1543 by means of a microcomputer, is to make use of an SPI (Serial Peripheral Interface), should this be available in the microcomputer. The TMS370 from Texas

Instruments and the MC68B11 from Motorola used in this application both are provided with this SPI interface.

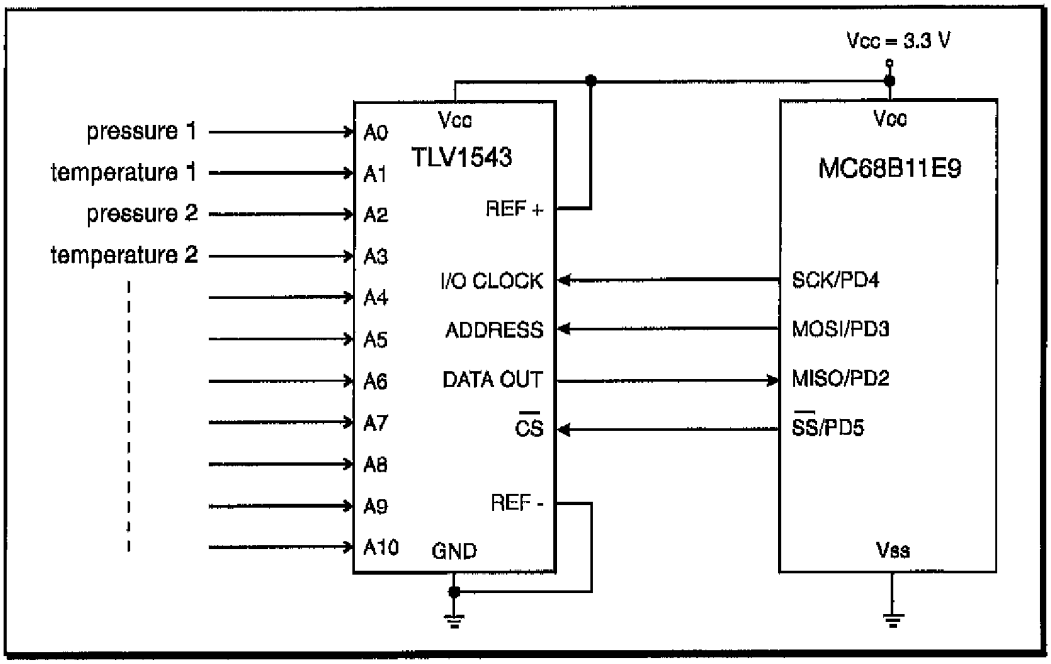

Figure 6.4: Interface of TLV1543 to MC68B11

The circuit diagram of the interface between the A/D converter TLV1543 and the microcomputer MC68B11, which is provided by an SPI, can be seen in Figure 6.4. The positive reference voltage connection of the A/D converter is taken directly to the supply voltage Vcc, and the negative reference voltage connection directly to the ground potential GND. The four digital interface connections SCK/PD4, MOSI/PD3, MISO/PD2 and $\overline{SS}/PD5$ are connected directly to the terminations of the TLV1543. A detailed description of this interface follows in the next section.

6.4.1 Serial Peripheral Interface SPI

The SPI (see Figure 6.5) consists of a serial 8-bit shift register, which is first loaded with the control data which needs to be sent to the input (ADC Input) of the analog-digital converter.

As a result of the loading of this register, the SPI transfer is simultaneously begun. A microprogram now automatically controls the serial transfer of the control data from the MOSI (*Master Out Slave In*) connection of the microcomputer to the ADC input. At the same time, there occurs the transmission of the data of the previous conversion results from the analog-digital converter to the MISO *(Master In Slave Out)* pin of the microcomputer. This data is loaded into the shift register. At the end of a transmission cycle (8 Bit), the contents of the shift register are automatically loaded into the buffer READ DATA BUFFER, from where the program can then be used to read out the data.

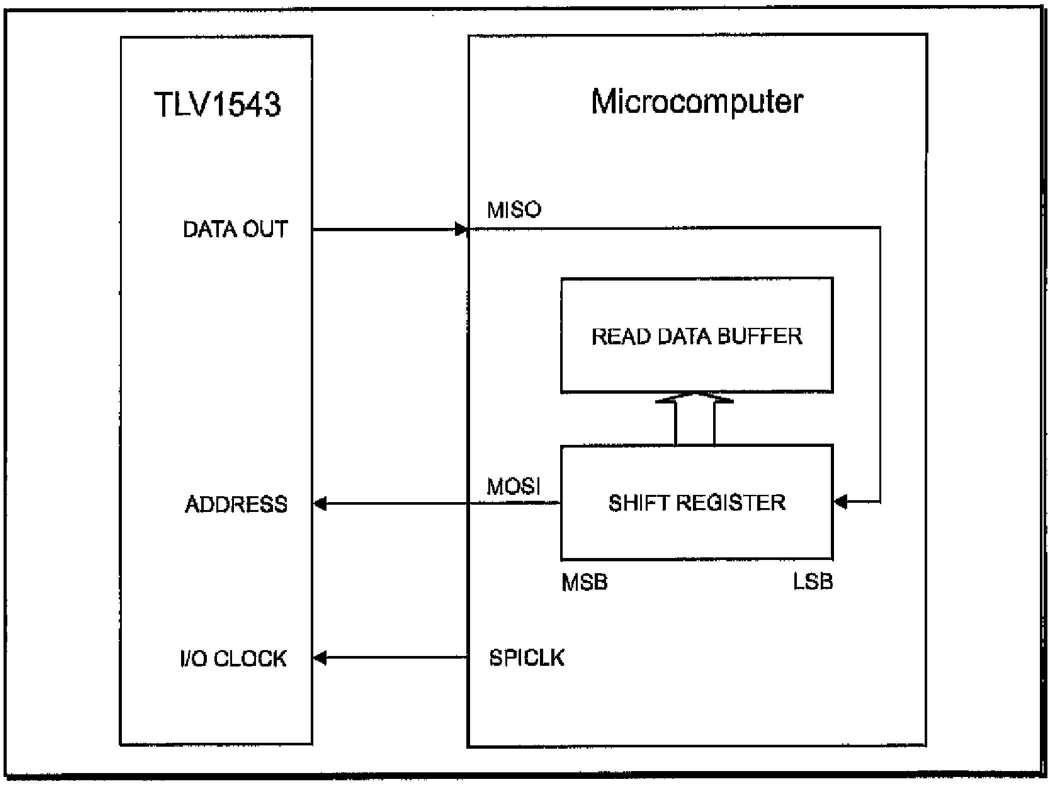

Figure 6.5: The internal structure and data flow of the SPI

The SPI is thus provided with the following features:

- simultaneous data input and output
- synchronous processing
- shift clock pulse SPICLK with programmable frequency
- internal flag to indicate the ending of a transmission cycle

The following SPI registers are decisive for communication via the SPI interface:

- Serial Peripheral Control Register (SPCR)
- Serial Peripheral Status Register (SPSR)
- Serial Peripheral Data I/O Register (SPDR)
- Data Direction Control Register (DDRD)

6.4.1.1 Serial Peripheral Control Register (SPCR)

The bit rates of the SPI's can be programmed by means of Bit 0 and Bit 1 of this register. Depending on the position of these bits, the frequency of the SPICLK will be 1/2, 1/4, 1/16 or 1/64 of the clock frequency of the processor.

The data transfer format is set by means of Bit 2. This bit must be set to 0 for correct operation with the TLV1543. Bit 4 of this register must be set to 1, in order to make the microcomputer be the Master. The SPI is switched on when a 1 is loaded in Bit 6.

6.4.1.2 Serial Peripheral Status Register (SPSR)

An important bit in this register is Bit 7 (SPIF). A 1 indicates that a transfer of data between the microcomputer and the TLV1543 has been completed. In the program, by means of a loop the status of the data transfer is thus also requested.

6.4.1.3 Serial Peripheral Data I/O Register (SPDR)

If the Bit SPIF of the register SPSR is set to 1, then the register SPDR contains the information received from the A/D converter. It can now be read out and additionally processed as required.

6.4.1.4 Data Direction Register (DDRD)

The Bits 5, 4, 3 and 2 of the register DDRD are occupied by the SPI interface when this is active. The communication to the TLV1543 is set by means of contents of this register. Bit 5 is declared as being an output register, so that Pin $\overline{SS}$/PD5 controls the Chip Select connection of the A/D converter. The SCK output (clock) is activated by means of Bit 4, and the microcomputer defined as Master by means of Bit 3 and Bit 2. This register must thus be loaded with the data word 58 Hex.

6.4.2 Timing Relationship of the TLV1543 and SPI

8 bits are transmitted at every data transfer which is made via the SPI interface. Since the A/D converter in the TLV1543 has a resolution of 10 bits, the data transfer must be performed twice, in order to get a complete conversion result. The pulse timing diagram for the transmission of a complete conversion result is shown in Figure 6.6.

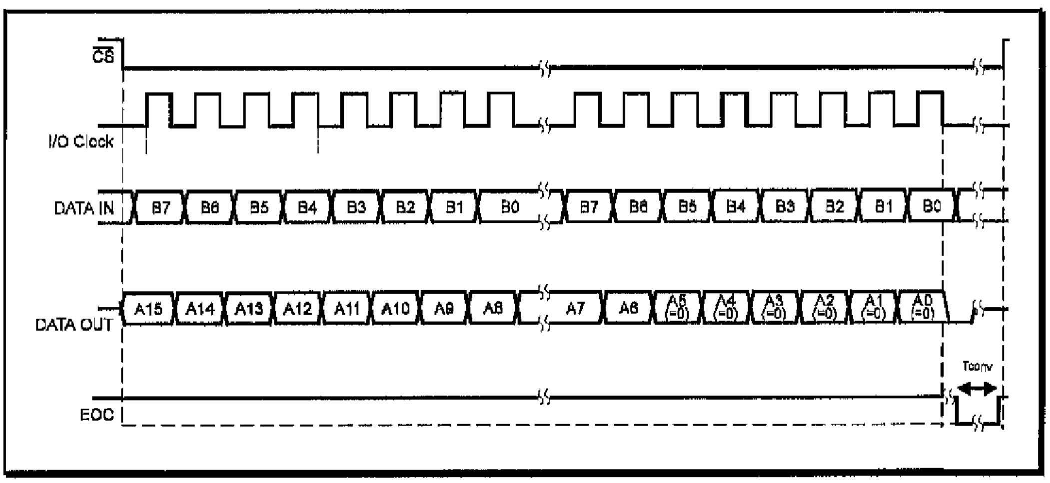

Figure 6.6: Pulse timing diagram for data transfer from TLV1543 to SPI

6.4.3 The program of the MC68B11

The program for the interface of the TLV1543 to the MC68B11 is given in Program List 2. It shows how the A/D converter TLV1543 is controlled by the microcomputer MC68B11 via the SPI interface, and how the conversion result is

read out. In addition, the configuration of the SPI interface can be seen in this program.

```
                * * * * * * * * * * * * * * * * * * * * * * * * *
                *                                               *
                * This program shows an example of how the      *
                * function of the A/D Converter TLV1543 can be  *
                * controlled with the use of an SPI interface,  *
                * and how the conversion results can be be      *
                * read out.                                     *
                *                                               *
                * * * * * * * * * * * * * * * * * * * * * * * * *
1000      BASEADD EQU   $1000          Register Offset Address
0008      PORTD   EQU   $08            Port D Data Register
0009      DDRD    EQU   $09            PORT D Data Dir Register
0028      SPCR    EQU   $28            SPI Control Register
0029      SPSR    EQU   $29            SPI Status Register
002a      SPDR    EQU   $2A            SPI Data Register
01f0      MSBYTE  EQU   $1F0           MSBYTE Address
01f1      LSBYTE  EQU   $1F1           LSBYTE Address
01ff      MEMOL   EQU   $01FF          Memory Location Low Byte
01fe      MEMOH   EQU   $01FE          Memory Location High Byte
01f       COUNTER EQU   $1F2           Loop Counter
01f3      CHANNEL EQU   $1F3           Channel Number

b600                  ORG  $B600       Start Address
b600 8e               LDS  #$0041      Set Pointer to Stack
b601 00
b602 41
b603 ce               LDX  #BASEADD
b604 10
b605 00
b606 86               LDAA #$38        Load Accumulator with 38Hex
b607 38
b608 a7               STAA DDRD,X      Load DDRD with 38Hex
b609 09
b60a 86               LDAA #$50        Load Accumulator with 50Hex
b60b 50
b60c a7               STAA SPCR,X      Set SPI as Master
b60d 28
b60e 86               LDAA #$10      Channel Number under Variable
b60f 10
b610 b7               STAA CHANNEL   Store CHANNEL
b611 01
b612 f3
b613 86               LDAA #$01        Load COUNTER for program
b614 01                                pass repeated twice
```

```
0035 b615 b7          STAA COUNTER
     b616 01
     b617 f2
0036 b618 bd  LOOP    JSR  TLV1543     Start conversion
     b619 b6
     b61a 27
0037 b61b bd          JSR  STORE       Store result
     b61c b6
     b61d 52
0038 b61e b6          LDAA COUNTER     Routine
     b61f 01
     b620 f2
0039 b621 4a          DECA             for a
0040 b622 b7          STAA COUNTER     program pass
     b623 01
     b624 f2
0041 b625 26          BNE  LOOP        repeated twice
     b626 f1
0043                  END
0044
0045 b627 86  TLV1543 BSET PORTD,X#$20 Set Chip Select to High
     b628 08
     b629 20
0047 b62a 86          LDAA #$02        Chip Select = High
     b62b 02
0048 b62c 4a  CSHIGH  DECA             for at least 21 us
0049 b62d 26          BNE  CSHIGH
     b62e fd
0050 b62f 1d          BCLR PORTD,X#$20 Switch Chip Select to Low
     b630 08
     b631 20
0051 b632 b6  MSB     LDAA CHANNEL     Load channel
     b633 01
     b634 f3
0052 b635 a7  STAA    SPDR,X           Send channel to ADC
     b636 2a
0053 b637 1f  LOOP1   BRCLR SPSR,X#$80 LOOP1     If SPIF=0, --> LOOP1
     b638 29
     b639 80
     b63a fc
0054 b63b a6         LDAA SPDR,X  Load received data in accumulator
     b63c 2a
0055 b63d b7         STAA MSBYTE  Store accumulator contents in MSBYTE
     b63e 01
     b63f f0
0056 b640 b6  LSB     LDAA CHANNEL     Load channel
     b641 01
```

```
b642 f3
b643 a7         STAA SPDR,X      Send channel to ADC
b644 2a
b645 1f  LOOP2  BRCLR SPSR,X#$80 LOOP2      If SPIF=0, --> LOOP2
b646 29
b647 80
b648 fc
b649 a6      LDAA SPDR,X  Store received data in accumulator
b64a 2a
b64b b7      STAA LSBYTE  Store contents of accumulator in LSBYTE
b64c 01
b64d f1
b64e 39  RETURN  RTS

b64f b6  STORE   LDAA MSBYTE       Load Accumulator A with MSBYTE
b650 01
b651 f0
b652 f6          LDAB LSBYTE       Load Accumulator B with LSBYTE
b653 01
b654 f1
b655 04          LSRD              Formatting of the converted
b656 04          LSRD              ADC value
b657 04          LSRD
b658 04          LSRD              A15 A14 A13 ... A7 A6 A5
b659 04          LSRD              MSB                    LSB
b65a 04          LSRD              A4, A4, A3, A2, A1 and A0=0
b65b b7          STAA MEMOH        Store in MEMOH
b65c 01
b65d fe
b65e f7          STAB MEMOL        Store in MEMOL
b65f 01
b660 ff
b661 39  RETURN  RTS
```

Program List 2

The setting of the channel number and of the test mode is performed by means of the variable CHANNEL. The addressing is done in the same way as with the interface of the TLV1543 to the TMS70C42, as can be seen in Table 1 and Table 2.

7. PROGRAM FLOW-DIAGRAM

The complete program for measuring values of pressure can be constructed according to the flow diagram shown in Figure 7.1.

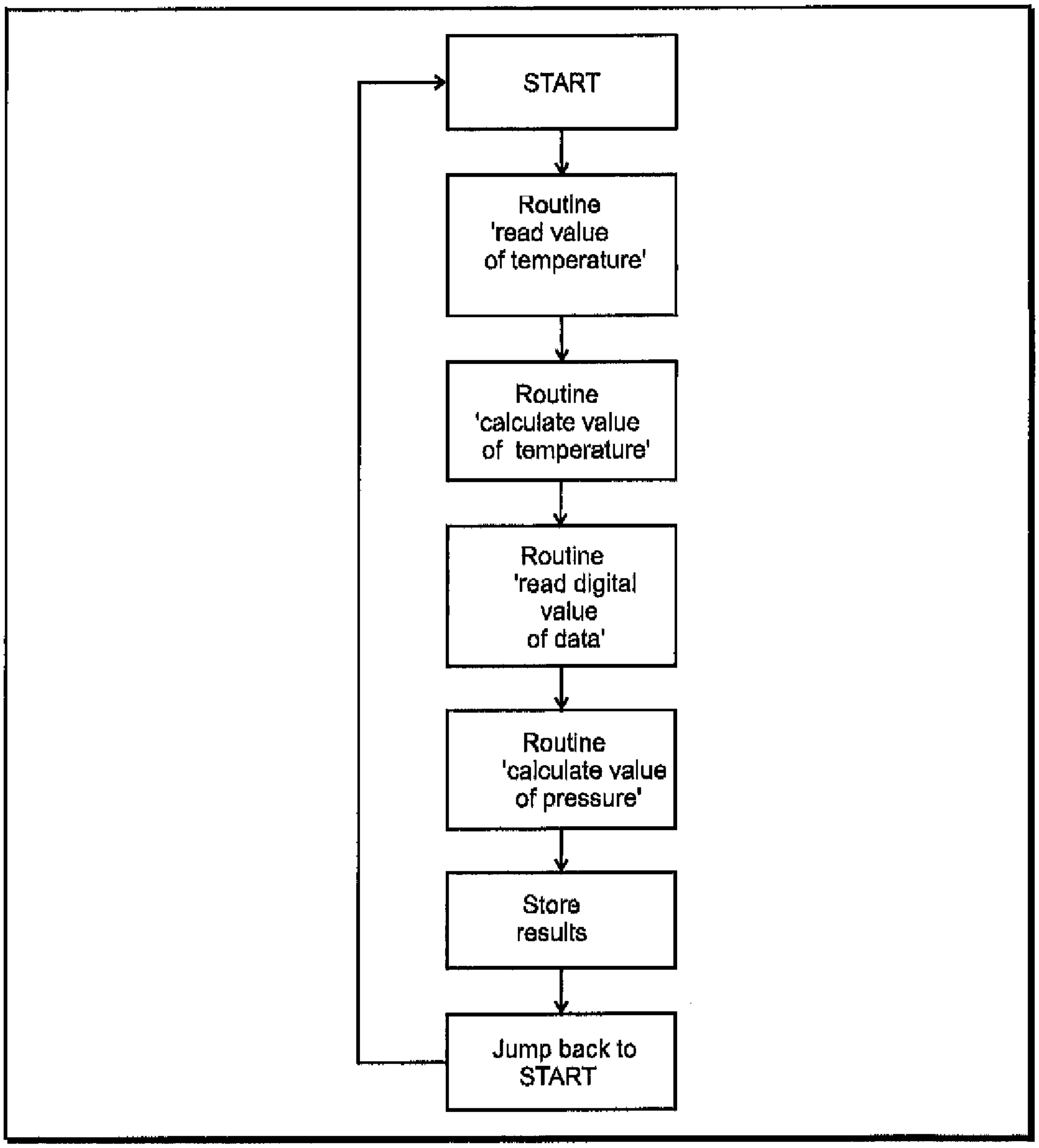

Figure 7.1: Program flow-diagram

8. CIRCUIT CONSTRUCTIONAL DETAILS

In particular when using analog circuits, careful attention to the layout of the circuit on the printed circuit board is essential, if the system is to operate without giving problems. A proposal for the layout of the wiring of the part of the circuit concerned with temperature measurement is shown in Figure 8.1.

This circuit operates with a single supply voltage for both the digital and the analog components. The supply to the analog circuitry must be free from interference voltages, such as hum and high-frequency voltage peaks. High-frequency interference from the digital part of the circuit is kept away from the supply voltage of the analog part of the circuit, by means of the inductance coil L1 and the blocking capacitor C3. Low-frequency interference is suppressed with the use of an additional electrolytic capacitor C5. In contrast with the digital part of the circuit, where attention must be paid to achieving low inductance by keeping connections as short as possible, with analog circuits it is common practice to connect the individual parts of the circuit in a star configuration to precisely defined central supply points: namely, to the central analog Vcc- and Ground points. In this way, it can be prevented that interference voltages in a wire loop are coupled into other parts of the circuit via common supply lines. The supply voltage is also fed in at these points. The filtering capacitors C3 and C5 are also situated here. Particular attention must be paid to the central analog grounding point. With the correct layout of the conductors, ground loops, and thus the undesirable coupling of the individual measurement data signals, can be avoided. If such coupling were to occur, it would inevitably cause errors in the measurement results. The reference voltage connections of the A/D converter belong to the analog part of the circuit. They are therefore also connected directly to the central points "analog V_{cc}" and "analog Ground".

An R/C network is connected to the non-inverting input of the operational amplifier, which operates as an impedance converter. In this way, high-frequency interference coupled in via the sensor is suppressed. Even when the frequency spectrum of such interference is generally to be found far beyond that at which the operational amplifiers can operate, there exists the danger that these voltages will be rectified by the non-linear characteristics of the semiconductors, and will then be added to those of the desired measurement signal.

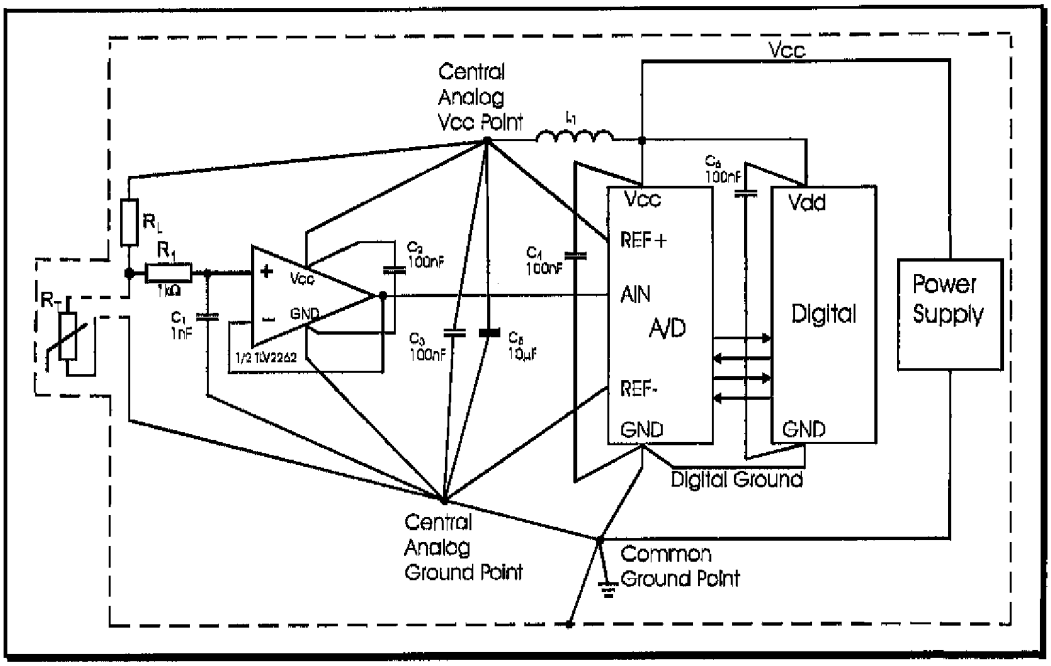

Figure 8.1: Proposal for wiring layout

The analog-digital converter TLV1543 used in this application is provided with only a single common ground connection GND, for both the internal analog and digital parts of the circuit which it contains. The supply voltages of the analog and digital parts of the circuit are now also taken to this ground connection. It is recommended in this case to provide a large grounded area under the A/D converter. A proposal for the laying out of the A/D converter TLV1543 is shown in Figure 8.2. The analog and the digital grounds are together taken - as shown in Figure 8.1 - to a common grounding point. The screening and grounding connections, if these are available, are also taken to this common grounding point.

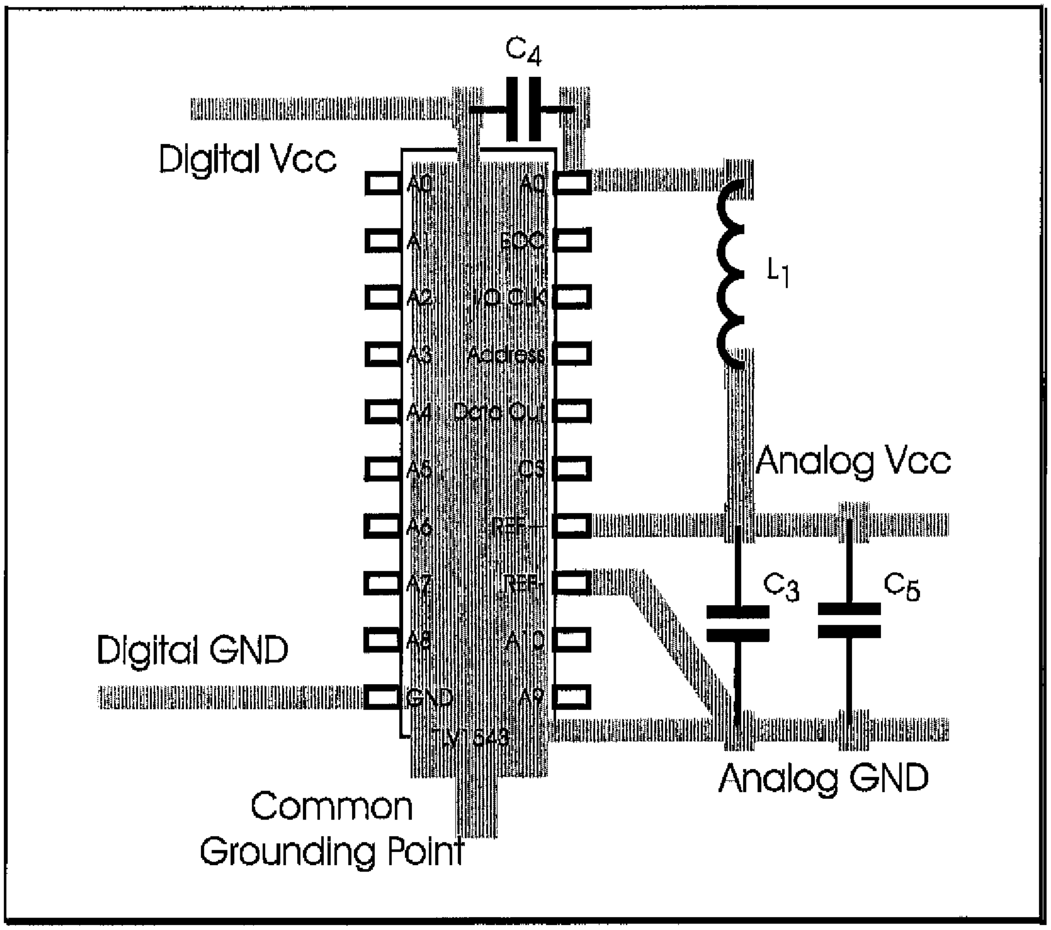

Figure 8.2: Layout proposal for the TLV1543

An additional important point when laying out the circuit board is the placing of the blocking capacitors relative to the individual active components. Blocking capacitors are necessary for two reasons. Firstly, they should ensure that the feed of the supply voltage remains with a low impedance, even at high frequencies; in this way, undesirable feedback paths and the intercoupling of different parts of the circuit can be avoided. On the other hand, these capacitors should quickly provide the energy required when there are rapid changes of load. This last point applies particularly - but not exclusively - with digital circuits. In order to fulfill the high-frequency requirements, ceramic capacitors are used for blocking purposes, having a capacitance of 100 nF. In analog circuits, care must also be taken that there are extremely low interference voltages, over a wide frequency range, on the supply voltage lines. For this reason, at this point additional blocking capacitors having a large capacitance (electrolytic capacitors, C = 50 µF) should be provided.

In conclusion in should again be mentioned that the use of analog and digital grounding levels (which must obviously be kept separate) makes good sense, in order to reduce the impedance of the return lines. Such levels are easily accessible for all components, and this simplifies considerably the layout of the circuit board. It should, however, be mentioned that without separate ground levels, but with a

careful layout of components and conductors, almost the same performance can be achieved.

9. REFERENCES

TMS7000 Family Data Manual	Texas Instruments
MC68HC11 Reference Manual	Motorola
TLV1543 Data Sheet	Texas Instruments
Semiconductor Sensors Data Handbook	Philips